REPORT 1093-28

REPORT
by
THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION
COLUMBUS, OHIO 43212

Sponsor	National Aeronautics and Space Administration Office of Grants and Research Contracts Washington, D. C.
Grant Number	NsG-74-60
Investigation of	Receiver Techniques and Detectors for Use at Millimeter and Submillimeter Wavelengths
Subject of Report	Annual Summary Report 1 September 1964 to 30 September 1965
Submitted by	Antenna Laboratory Department of Electrical Engineering
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ANNUAL SUMMARY REPORT
(1 September 1964 - 30 September 1965)

I. INTRODUCTION

This report summarizes the results obtained on research programs under NASA Grant NsG-74-60 during the period 1 September 1964 to 30 September 1965, and briefly outlines the program planned for the period 1 October 1965 to 30 September 1966.

II. RESEARCH RESULTS FROM 1 September 1964 to 30 September 1965

The semi-annual report[1], dated 28 February 1965, discussed the results obtained from 1 September 1964 to 28 February 1965. These results included completion of the evaluation of the interferometric receiver for the submillimeter-wavelength radiometer[2,3], publication of the work on the cross-relaxation maser[4,5], and publication of the study of the effects of non-zero bandwidths upon second-order, nonlinear, optical interactions[6,7]. A portion of the study on the low-temperature carbon bolometer was prepared as a paper and has been accepted for publication[9]. Work had also begun on the submillimeter-wavelength laser and on the vacuum chambers and the carbon furnace necessary to adapt the submillimeter-wavelength interferometric receiver to the study of submillimeter-wavelength absorption in simulated atmospheres, utilizing the space-propagation facilities of the Antenna Laboratory[1,10].

The remainder of this section is concerned with the results obtained since 28 February 1965.

A. Solar Radiation Measurements

During the latter part of March and the month of April, 1965, the interferometric receiver was moved to Kitt Peak National Observatory, located about 50 miles west of Tucson, Arizona, where it was coupled to one of the auxiliary heliostats of the McMath Solar Telescope.* Inclement weather necessitated staying about two weeks longer than planned and prevented the researchers from obtaining the quality and quantity of data desired; however, some very good results were still obtained. Measurements were made of the solar and sky radiation at a number of different zenith angles and with the total water-vapor content of the atmospheric path ranging from less than 0.2 to about 0.5 precipitable centimeters. Solar radiation was observed in several atmospheric windows between 300μ and one mm wavelength. In particular, the transmission of the window centered at a wavelength of 345μ was measured and determined to be about 1.7 per cent under the conditions of a 30° zenith angle and 0.17 cm of precipitable water vapor along the path. These data, which are discussed in Report 1093-27[11], were presented at the Boulder Millimeter and Far-Infrared Conference, 30 August 1965, and were included in a written paper which has been submitted for consideration for a special IEEE Proceedings issue on millimeter waves[12]. Chart I shows one of the spectral plots obtained with a total precipitable water-vapor content in the solar path of about 0.17 cm. The solar radiation power (temperature) is plotted as a solid line and the sky radiation power (temperature) is plotted as a dashed line. The zero reference line represents the temperature of the chopper blade (slightly above room temperature). The peak of the 345μ solar window represents about 373°K and the minimum of the sky radiation curve at the same wavelength is about 273°K. Thus, the difference is about 100°K, or 100/6000 the difference which one would expect to see if there were no atmospheric attenuation or radiation to contend with.

During the stay at Kitt Peak a theoretical paper was written concerning the use of prolate spheroidal wave functions in improving the resolution of interferometric receivers (interference spectrometers), and this paper has been accepted for publication by the Journal of the Optical Society of America[13]. Basically, the resolution of the interference spectrometer is limited by the maximum difference which can be obtained between the two path lengths in the Michelson interferometer, or, in other words, by the range of the argument of the interferogram

* These measurements were supported in part, by funds from the National Science Foundation to the Association of Universities for Research in Astronomy, Tucson, Arizona.

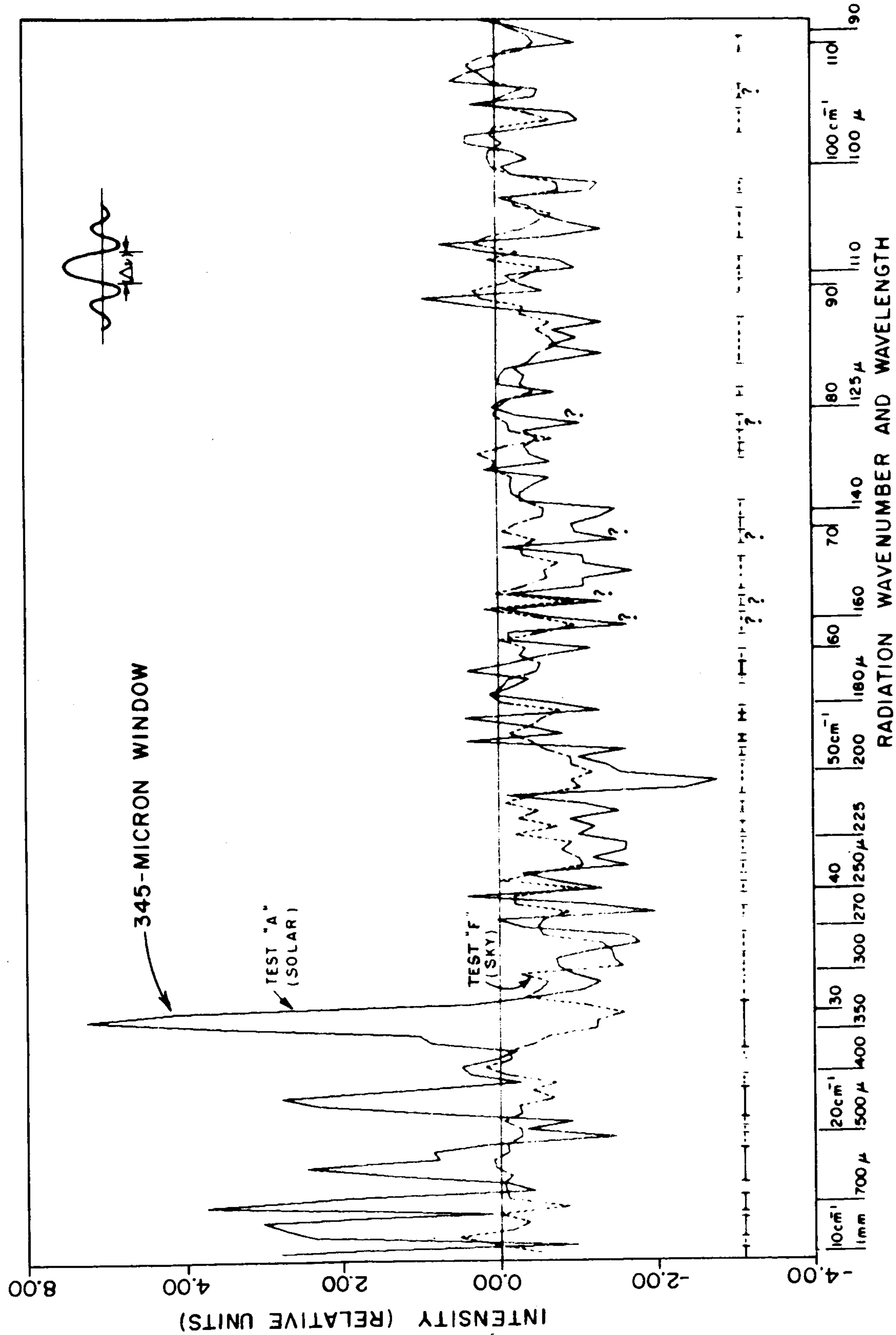
345-MICRON WINDOW
TEST "A" (SOLAR)
TEST "F" (SKY)
INTENSITY (RELATIVE UNITS)
8.00
4.00
2.00
0.00
-2.00
-4.00
RADIATION WAVENUMBER AND WAVELENGTH
10cm⁻¹ 1mm
700 μ
20cm⁻¹ 500 μ
400
350
30
300
270
40
250 μ
225
50cm⁻¹ 200
180 μ
60
160
140
70
125 μ
80
90
110
100cm⁻¹ 100 μ
110
90

Chart I

function which can be experimentally obtained. In a practical sense the length of the interferogram is limited by such experimental factors as diffraction effects, mechanical limitations of the interferometer mechanism, and the length of time available for experimental observation. The latter limitation is especially severe when one is making spectral measurements of solar radiation. However, since the interferogram is an analytic function, it should be possible to expand it in a series of orthogonal functions; and then to extend it to values of the argument larger than those utilized in the experimental measurement, provided that the set of expansion functions is still complete and orthogonal on the larger interval. A set of functions which meets this requirement is the set of prolate spheroidal wave functions, and the JOSA paper discusses how they may be used to extend the interferogram function and thus improve the instrument resolution. It also discusses the price which must be paid for this increase in resolution (i.e., a lower signal-to-noise ratio).

B. Water Vapor Absorption Measurements

After the interferometric receiver was returned from Kitt Peak, work was begun on adapting it for use with one of the Antenna Laboratory's 50-foot-long White absorption cells [10] (see Fig. 1). A high-temperature carbon furnace for use as the source had been completed and the cells readied for use. The entire system has now been assembled and a series of evaluation tests is under way. After some minor modifications are made* this will be an outstanding facility for the measurement of the long-path submillimeter-wavelength absorption properties of all types of simulated atmospheres, including simulated planetary atmospheres.

C. The Submillimeter-Wavelength Laser

In March, 1965, the 5.5-meter-long submillimeter laser was completed sufficiently to allow operation with continuous dc excitation. Laser action was observed at 3.39μ wavelength using a helium-neon gas mixture.

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* These modifications will consist primarily of a new solid-state analog-to-digital conversion system and an arrangement to permit the adjustment of the instrument optics while the instrument is under vacuum.

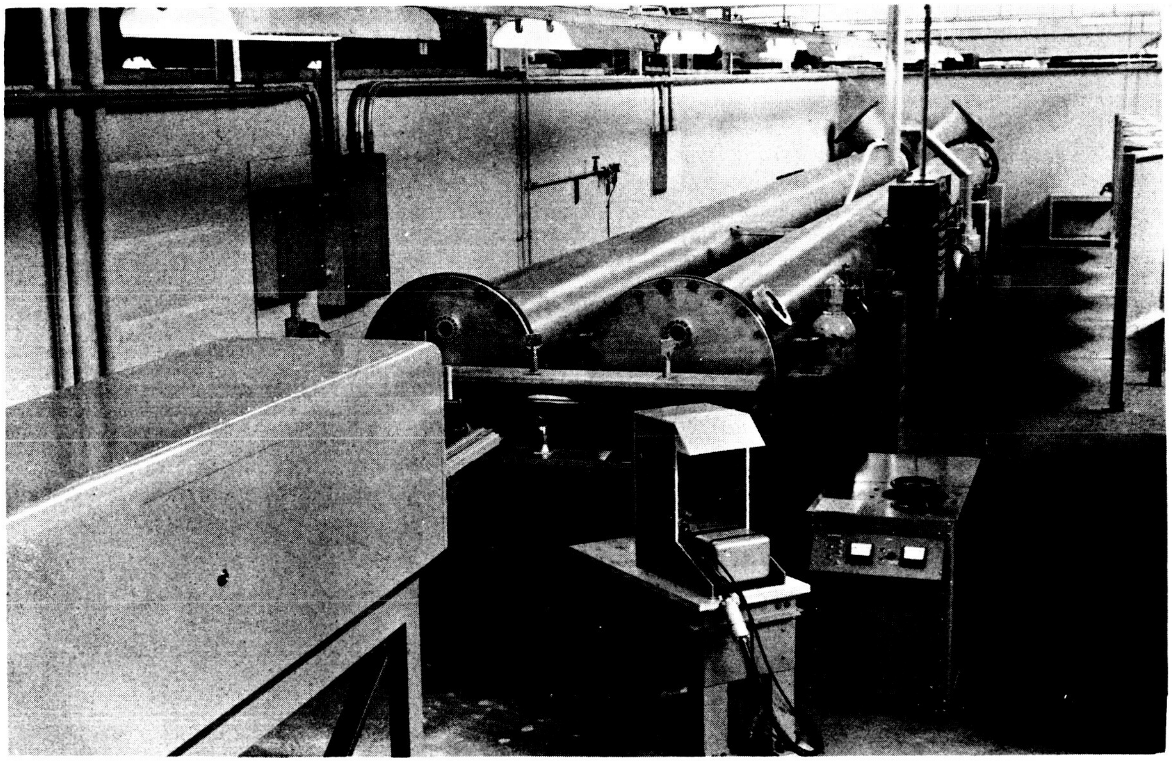

Fig. 1. The long path absorption cell equipment.

All attempts to observe laser action at longer wavelengths using pure neon gas and continuous excitation were unsuccessful. Modifications were made on the laser to allow it to be excited by a high-voltage radar pulser. In this mode of operation, using a mixture of carbon dioxide and air as the active medium, laser action has been observed in the 10.6μ wavelength region, with a peak power output of about 4 watts. The optical cavity is now being changed to increase the volume of active gas contributing to the laser action, thus allowing greater power output to be obtained.

Construction of a 1.5-meter-long laser, designed specifically for 10.6μ operation has been started. It differs from the 5.5-meter laser in that the mirrors forming the optical cavity are external to the tube containing the active medium and the discharge electrodes. Optical coupling to the active medium is through Brewster-angle windows of sodium chloride. No tests have yet been made on this laser. Both lasers will be used in studying the processes of laser excitation action in the far-infrared and submillimeter-wavelength regions.

III. RESEARCH PLANS FOR THE PERIOD 1 October 1965 to 30 September 1966

A. Study of Submillimeter-Wavelength Atmospheric Absorption

The absorption of submillimeter-wavelength radiation in the Earth's atmosphere results primarily from atmospheric water vapor and carbon dioxide; to a lesser extent from collision-induced absorption in nitrogen and oxygen; and, in the higher atmospheric layers, also from ozone. Following the initial functional tests and possible improvements on the interferometric receiver - White absorption cell combination (which will be carried out in the first few weeks of the new grant period), it is planned to start a program of long-path water-vapor absorption measurements to determine the effect of a path length, water-vapor partial pressure, and the partial pressure of non-absorbing atmospheric gases upon the absorption of submillimeter radiation by atmospheric water vapor. These measurements will be carried out by making measurements of the water-vapor absoprtion at a number of different pressures for several different path lengths, starting with a path length of 200-feet and increasing in increments of 100-feet, up to the maximum path length which the instrument signal-to-noise ratio will permit. Following these basic results the effects of pressure broadening upon the water-vapor absorption will be measured, and then the absorption of other gases present in the atmosphere, singly and in combination with each other, will be studied.

Other gases, not present to any substantial degree in the Earth's atmosphere, but postulated to be present in the atmospheres of the other planets of the solar system, will also be studied as time permits. The data obtained on these experiments should enable one to predict the total absorption which a beam of submillimeter wavelength radiation would encoutner during passage through any portion of the atmosphere.

B. Submillimeter Laser Study

It is planned to study the carbon-dioxide laser and to attempt to learn more about the mechanisms responsible for the enhancement of the lasing action in this device. Impurities such as oxygen and water vapor are known to increase the lasing action. Once these enhancement mechanisms are understood it is hoped that they can be extended to other laser systems in order to obtain laser action at the longer wavelengths which are of interest to us. A study of the energy level systems of some other gases which might be suitable for laser use in the submillimeter region has already been begun. This study included the possibility of finding systems with energy levels close to the metastable vibrational levels of the N_2 molecule so as to use the efficient resonant transfer of energy from the N_2 excited vibrational state to the molecule in question. It is hoped that systems will be found from which longer wavelength coherent light in the far infrared region will be generated with better efficiency than can be obtained from atomic gas lasers.

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